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Applying BASIC SOIL WATER DATA to Water Control Programs in Everglades Peaty Muck

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CONTENTS

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APPLYING BASIC SOIL WATER DATA TO WATER CONTROL PROBLEMS IN EVERGLADES PEATY MUCK[1]

by

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INTRODUCTION

Successful crop production on the organic soils of the Florida Everglades depends on effective control of soil water. Availability of water stored in Lake Okeechobee or in conservation reservoirs, high permeabilities, and presence of an underlying relatively impervious limestone and/or marl layer at shallow depths all combine to make subirrigation an economical practice in the northern section of the Everglades. Underdrainage is then needed to provide storage for heavy rains without flooding the root zones. Normally the farm layout made up of ditches and mole drains suffices for both irrigation and drainage.

The cultivated soils in this organic tract now average not more than about 5 feet in depth and are subsiding at an average rate of about 1 inch per year (12).[3] This decrease in the thickness of the organic layer, mainly by biochemical oxidation, produces a corresponding reduction in the vertical cross sectional area that is available for the transport of water to and from drains. As a result the complexity of the water control picture increases with time. The decreasing depth to rock eventually renders underdraining with moles impracticable.

The future of the area, therefore, will depend to a great extent on developments in the field of water control. Certainly the possibility for modification of existing irrigation and drainage practices or the initiation of new ones should be explored. Any appraisal of this sort will require an understanding of certain phenomena of soil water, presented herein.

Although information is available on design criteria for this area (2, 5, 6, 11, 17), much of the more fundamental data are lacking, including detailed soil-water-holding and saturated-flow characteristics.

This report presents particular basic soil and water data for a typical Everglades organic soil. These data have been examined to determine where and how they can be used to assist in the solution of the water control problems encountered.

PROCEDURE

The studies involved were physical rather than chemical in nature. Conclusions are developed from data which had been obtained through standard-laboratory-procedure tests of undisturbed soil cores from the profile of a typical Everglades peaty muck. The

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[1] Cooperative research by the Eastern Soil and Water Management Research Branch and the Watershed Technology Research Branch of the Soil and Water Conservation Research Division, Agricultural Research Service, USDA; the Florida Agricultural Experiment Station; and the Central and Southern Florida Flood Control District.

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[3] Numbers in parentheses refer to Literature Cited at end of report.

particular soil has been under cultivation for more than 20 years and presently has an average depth of about 4 feet. It is underlain by relatively impervious lime rock.

Bulk densities, organic matter contents, and vertical saturated hydraulic conductivities were determined from 3-inch-high vertical cores 3 inches in diameter, from Blocks I, VI, and VIII of a water table experiment in progress at the Everglades Experiment Station.[4] Each block has an area of about 2 acres. The soil layers of the 0-3, 3-6, 6-9, 9-12, 13.5-16.5, 19.5-22.5, 25.5-28.5, and 32-39 inch levels were sampled at 4 locations in each of the 3 blocks, giving a total of 12 determinations at each depth for the soil properties mentioned. However, measurements of moisture tension, air content, and water release, or storage, were determined from four samples alone for each of the depths listed.

Horizontal saturated conductivities are those reported in an earlier study by Harrison and Weaver (6). The cores in that study were obtained from land adjacent to the experimental area mentioned above.

All the samples taken for test were subjected to identical standard procedures. They were first thoroughly soaked for several days and then de-aired under about a 2/3 atm. vacuum. The fully saturated cores were first carefully weighed to determine their water content at zero tension. Other information was secured in the following order:

1. Saturated hydraulic conductivity (K)

2. Water content at various tensions between 0 and 15 atm.

3. Bulk density

4. Organic matter content

Conductivity data were based on 15-minute steady percolation rates of de-aired water and a constant hydraulic gradient of 1.33 inches of water per inch of soil.

Moisture-tension relationships were developed from desorption water contents obtained with a sand-silt column and standard pressure membrane equipment. The intact 3-by-3-inch cores were used over the tension range between 0 and 100 cm. of water. Thin undisturbed subsamples taken from the center of the cores were used for the higher tension points.

Bulk densities were determined from oven dry weights of the recombined cores. Small subsamples from each core were then subjected to a standard dry ignition procedure to obtain organic matter contents.

RESULTS AND GENERAL CONSIDERATIONS

Moisture-Tension Characteristics

Average moisture-tension relationships for each of six soil depths in Everglades peaty muck are presented graphically in Figure 1.

Laboratory desorption periods in excess of 5 days were required to reach the equilibrium water contents shown. About 85 percent of the total desorption, however, took place within the first 24 hours. The remaining water continued to drain off slowly, taking about 4 days, possibly the result of retarded release from hydrophyllic substances and slow movement through the walls of intact plant cells. Slow release was in evidence over the entire range of tensions between 0 and 15 atm. This phenomenon is probably reciprocal to the slow reversibility on wetting displayed by organic soils. Both should be considered in the analysis of water control problems.

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[4] Part of the Florida Agricultural Experiment Station.

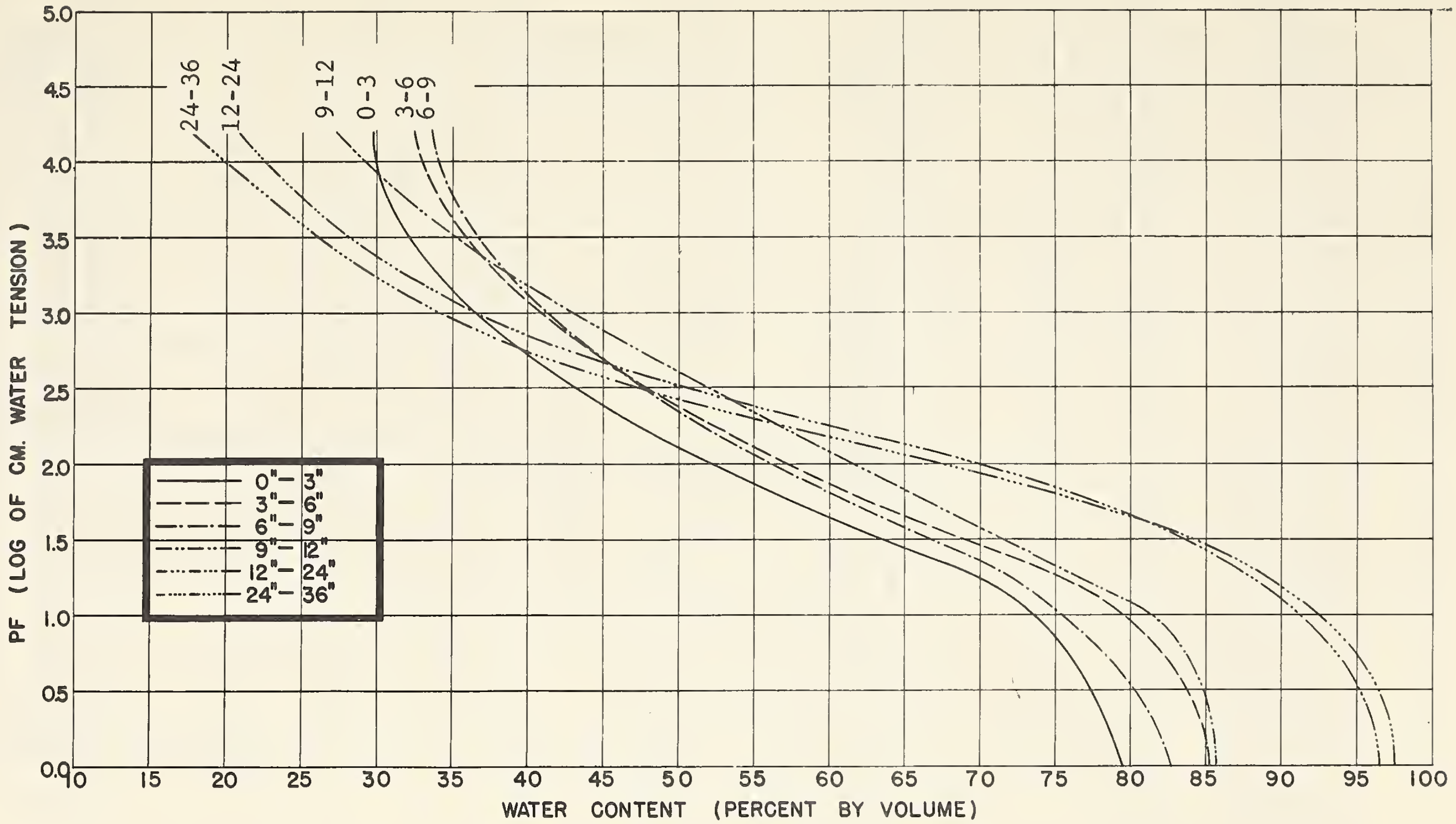

Figure 1. --Desorption moisture-tension relationships in Everglades peaty muck; data taken from Block I of the Belle Glade Water Table Study, January 1959.

Soil Air Content Above a Receding Water Table

Adequate soil aeration is the primary purpose of farmland drainage. Although supplying oxygen to plant roots in proper concentrations must be considered the most important function of aeration, the use of aeration as a criterion of optimum drainage levels has practical limitations. These limitations are chiefly due to a lack of instrumentation or other means for rapid and accurate gaging of soil oxygen concentrations in the field. Until such facilities become available it is necessary to resort to empirical methods for estimating minimum and optimum water-table levels.

Since diffusion is an important process in the transfer of oxygen from the outside atmosphere to the plant roots, its measure should give at least relative information on the aeration status of a soil. Diffusion rate is reportedly a linear function of the volume of air-filled voids (10, 13) if the pores are interconnected in such a way that the outside atmosphere is accessible to all of them. The air space contained by a soil above the water table may, under this condition, serve as a basis for estimating root zone aeration. The use of air space as a criterion for determining drainage requirements has been discussed by Baver (1).

The theoretical air distribution patterns above a receding water table may be determined from standard desorption moisture-tension curves. The method utilizes the theory that at equilibrium the tension at any given point in the unsaturated profile is numerically equal to its height above the free-water surface. In this way the equilibrium water content at any point above the water table may be ascertained. Its complement, the air content, may be simply determined by subtracting percent volume of water content from percent volume of water content at saturation.

The desorption curves of Figure 1 have been used to determine the values of air space given in Table 1. For this purpose the pF, or log tension scale, has been converted to centimeters of water tension. The distance between the center of any given layer and the water table was assumed to be equal to the average tension exerted in that layer. Air space was then computed as described.

TABLE 1.--*Air space contained in each 3-inch soil layer of Everglades peaty muck for a receding water table*

Depth to Water Table (inches)	Air Space (percent of soil volume) Per Indicated Soil Layer (inches)									
	0-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	27-30
0..........	0	0	0	0	0	0	0	0	0	0
3..........	3	0	0	0	0	0	0	0	0	0
6..........	7	3	0	0	0	0	0	0	0	0
9..........	11	7	3	0	0	0	0	0	0	0
12.........	15	11	8	2	0	0	0	0	0	0
15.........	18	15	11	6	2	0	0	0	0	0
18.........	20	18	14	9	7	2	0	0	0	0
21.........	22	21	18	13	9	7	2	0	0	0
24.........	23	22	19	15	12	9	7	2	0	0
27.........	24	23	21	17	13	12	9	7	2	0
30.........	25	25	22	18	15	13	12	9	5	2

The information contained in Table 1 is useful for estimating the depth to which it is necessary to lower the water table after flooding, provided a foreknowledge exists of plant rooting habits and minimum air space requirements of the crops involved.

The method presumes that the entire soil profile will be initially saturated. This may or may not occur, depending mainly on rainfall duration and intensity. If the profile does not become initially saturated, actual air contents will probably be slightly higher than

those determined from desorption curves. Air entrapment reduces the probability of complete saturation under field conditions.

To prevent evaporation, the soil samples were covered on the tension table while awaiting examination. In nature, however, the air content above the gravity equilibrium point is increased by evaporation, which usually begins shortly after rainfall stops. This factor of evaporation, plus any air entrapment, tends to counterbalance the slow release of the last 15 percent of soil water, which required about 4 days under laboratory conditions to drain as described in the section on Moisture-Tension Characteristics. Therefore, under field conditions the air content of the muck after 1 or 2 days of drainage may actually be equal to, even greater than, the air content computed from the curves of Figure 1, or the figures of Table 1, both of which give the 5-day equilibrium rate. This, of course, does not detract from the value of the method for design work where a slight safety factor is desirable.

Bulk Density and Organic Content

Average bulk densities and organic content for the various soil layers are listed in Table 2. Bulk density data serve to characterize the local physical condition of this Everglades soil. They may also be used for the conversion of volume percentages of water content to dry weight percentages. This is done by dividing volume percentages of water by the bulk densities.

TABLE 2.--*Bulk density and organic matter content of various soil layers in Everglades peaty muck*

Soil Layer (inches)	Soil Bulk Density (gm/cc)	Organic Matter Content (% dry wt.)
0 - 3	0.356	85.5
3 - 6	.358	85.4
6 - 9	.336	85.2
9 -12	.290	86.0
13.5-16.5	.140	87.4
19.5-22.5	.130	86.9
25.5-28.5	.122	87.6
32 -39	.145	81.8

Saturated Hydraulic Conductivity

The saturated hydraulic conductivities, K, in inches per hour for various layers of Everglades peaty muck are listed in Table 3.

TABLE 3.--*Saturated hydraulic conductivity of Everglades peaty muck in the vertical and horizontal directions for various soil layers*

Soil Layer (inches)	Saturated Hydraulic Conductivity K (inches/hour)	
	Vertical	Horizontal[1]
0 - 3	12.5	--
3 - 6	10.5	13.8
6 - 9	16.6	--
9 -12	13.1	11.5
13.5-16.5	13.7	4.8
19.5-22.5	16.4	3.4
25.5-28.5	12.0	4.5
32 -39	6.0	--

[1] Taken from Harrison and Weaver (6).

There is little difference in vertical conductivity between depths until the 32 to 39 inch layer is encountered, where the presence of marl intimately mixed with the organic fraction results in a reduction of flow rate by about half. Horizontal rates are about equal to vertical rates in the tilled layer (top foot), but they are significantly less in the undisturbed zones where sedge leaf and stalk remains have their long axes oriented in the vertical direction. The vertical passageways are consequently less tortuous than those in the horizontal direction and offer little resistance to the flow of water.

Water Storage and Release Characteristics

It is often desirable to know how much rainfall a given soil will absorb without the occurrence of surface runoff. The design of drainage channels and control structures depends primarily on amounts of overland flow developed from rains falling in excess of the infiltration capacity of the soil. Most of south Florida's soils are flat surfaced and so highly permeable that surface runoff usually does not occur until the storage capacity has been fully utilized.

Storage capacity is approximately equal to air space existing in the soil profile before rain occurs. Where water tables are within 2 feet of the surface, usual for cultivated soils in this area, the desorption soil air contents of Table 1 should furnish a reasonably accurate basis for computing storage space. The air distribution above such shallow water tables is nearly constant. In cases where evapotranspiration exceeds capillary conduction rates, the moisture-air profile equilibrium is reestablished at night.

The use of desorption instead of sorption data for this purpose is logical, since the final condition of complete flooding implies that no tension exists at any point in the soil profile. The hysteresis complications introduced by a rising water table need not be considered except for water tables known to be rising before the onset of rain. For practical purposes, water tables of irrigation water may usually be assumed to be stationary after being lowered by previous drainage.

Storage space may be computed from the data of Table 1. This is done by converting all air space values existing above a given water table to equivalent inches of depth. For example where 15 percent air space exists the storage is equal to 0.15 inch per inch of soil. The total storage above a 12-inch water table is computed as follows:

$$\text{Storage} = 3 \times 0.15' + 3 \times 0.11' + 3 \times 0.08' + 3 \times 0.02' = 1.08''$$

This value of storage is also equal to the number of inches of water removed when the water table is lowered from the surface to a 12-inch depth. Storage and release values for various depths to water table are given in Table 4. Also given are the fractions of the soil volume drained above the water table as the freewater surface moves downward. This measure of drainable porosity is used frequently in the solution of drainage problems.

The use of sorption (rising water table) moisture contents furnishes information on freewater accretion in the profile where water tables are rising, as in subirrigation. Under these conditions changes in water content per unit rise in water table are somewhat less than the changes that occur when water tables are falling. This is due to hysteresis between the wetting and drying portions of the overall moisture-tension relationship.

Sorption data between tensions of 0 and 100 centimeters of water, together with limited intermediate scanning data, provided a means of plotting the water gain curves in Figure 2. The curves are of necessity only approximate because much of the scanning data were based on interpolation.

Also shown in Figure 2 is a complete water release curve, starting with a saturated profile, based on the data of Table 4. Other release curves for falling water tables starting at intermediate levels are appropriate only where water tables have first risen to the starting level shown and then fallen. In this case the only water available for

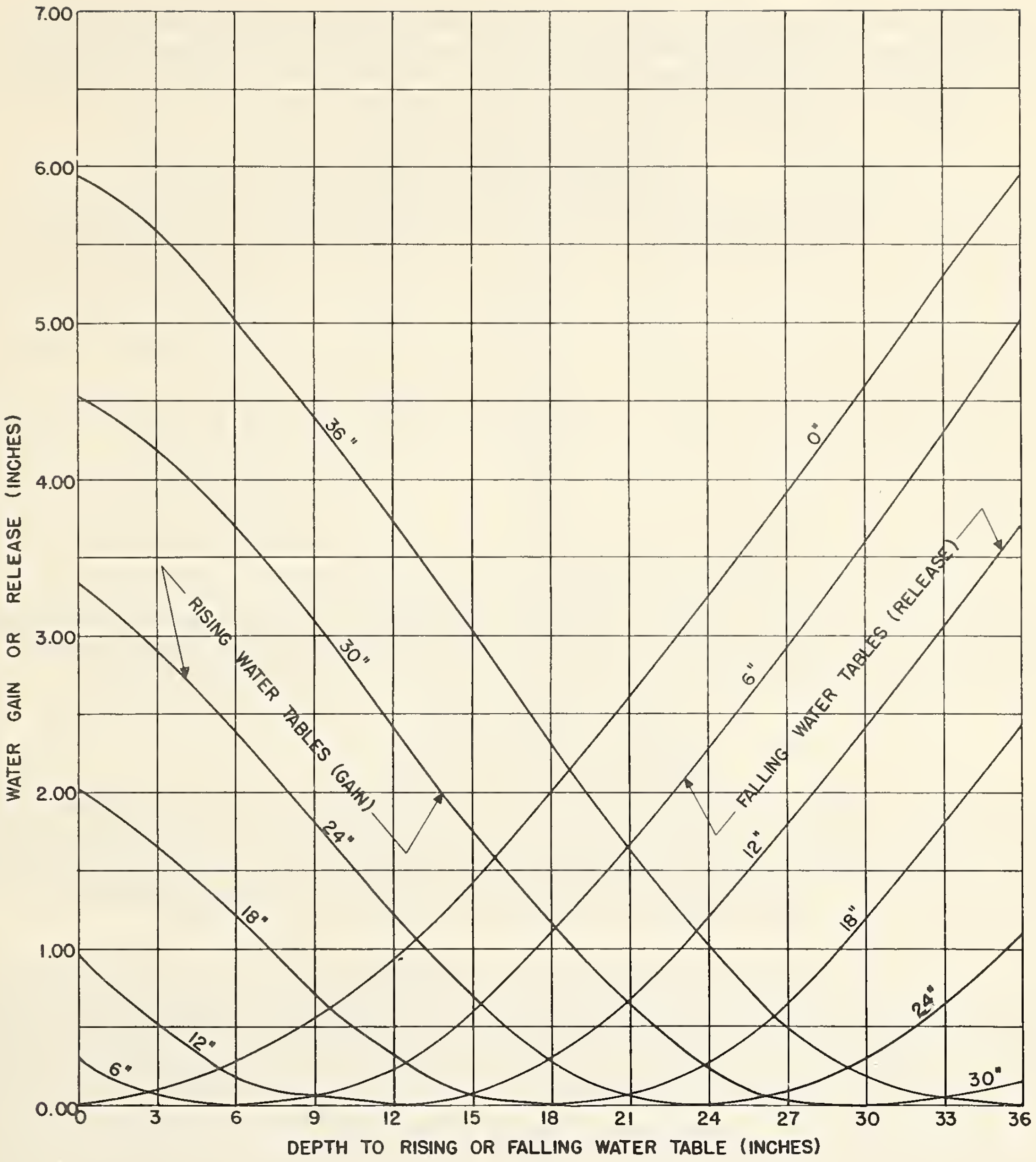

Figure 2.--Water gain and release characteristics for initial water table levels in Everglades peaty muck, based on sorption and desorption data from Block I of the Belle Glade Water Table Study.

TABLE 4.--*Water storage capacity, or water released, and fraction of soil volume drained in each 3-inch soil layer of Everglades peaty muck for a receding water table*

Depth to Receding Water Table (inches)	Total Water Storage Capacity, or Water Released (inches)	Fraction of Soil Volume Drained (f)[1]
0	0.00	0.00
3	.09	.03
6	.30	.05
9	.63	.07
12	1.08	.09
15	1.56	.10
18	2.10	.12
21	2.76	.13
24	3.27	.14
27	3.84	.14
30	4.38	.15

[1] f = water released/depth to water table.

release above the starting point are sorption contents. The information contained in Figure 2 can be used in estimating storage and release for fluctuating water tables.

DRAINAGE DESIGN

Adaptation to Flow Theory

Approximate required spacings of ditches or underdrains may be determined through use of numerical methods based on flow theory. In general, these methods all require a knowledge of saturated hydraulic conductivity, desired water removal rate, the vertical position of the drain with respect to the ground surface and to the impermeable layer when present, and the minimum depth to water table that can be tolerated.

Most of the workable approximations for calculating drain spacings stipulate that rainfall rate and water table position be constant throughout the critical period of drainage. These methods are directly applicable only to regions where rains of long duration and relatively constant intensity are common. Under these conditions it is wise to design drainage that will insure a safe minimum depth to water table for a given rainfall intensity.

As in the rest of the southeastern region of the United States, high intensity rains are prevalent in the Everglades. The "steady state" conditions of drainage, mentioned above as a stipulation in calculating drain spacings, as a rule do not occur in south Florida. Here, in agricultural practice the water tables are allowed to rise, thus permitting the storage capacity of the soil to be utilized. Drainage should then be capable of lowering the water level fast enough to prevent plant damage. Most crops will tolerate short periods of root zone flooding, making this a workable practice. It is generally agreed that such periods should not exceed 48 hours for truck crops.

Steady-state drain spacing formulas may be reconciled to the nonsteady-state or falling-water-table conditions in highly permeable soils if the water release characteristics of the profile are known. One adaptation as reported by Harrison and Weaver (6) requires that an appropriate steady-state formula first be solved for drain-discharge rate by use of a range of assumed values of spacing. The instantaneous discharge rates for a wide range of water-table positions may thus be determined for any assumed spacing. For a given spacing the time required for the water table to pass downward through each small layer of soil is next determined by dividing the water release attending the change in water table by the appropriate average instantaneous discharge. Finally,

the total time necessary to lower the water table from the ground surface to some safe level is found by summing the separate times required to cross the various small layers. The optimum spacing may then be selected by comparing all the drawdown times and choosing the widest spacing that allows adequate drainage for crop needs.

Interspacing Closed Drains

Three methods for determining approximate closed drain spacings have been applied to Everglades peaty muck. These are the methods of Hooghoudt, Ernst and Boumans, and Glover, the latter providing a nonsteady-state formula. The three methods are described and compared here.

Hooghoudt's Method

The tabular method of Hooghoudt (7) has been described by Van Schilfgaarde, Kirkham, and Frevert (15). The formula used is as follows:

$$S = 8Kd_e m/Q + 4Km^2/Q,$$

where S = spacing in meters

K = hydraulic conductivity in meters per hour

d_e = thickness of an "equivalent permeable" layer in meters (obtained from Hooghoudt's tables; depends on drain radius, spacing, and distance from the impermeable layer)

m = distance between water table and plane passing through drain axes, in meters

Q = discharge per unit length of drain in cubic meters per hour.

By rearranging terms, the solution for discharge becomes:

$$Q = \frac{4Km\,(2d_e + m)}{S}$$

In applying this formula Hooghoudt assumed a drain radius of 0.05 meter (2 inches) and a drain depth of 0.76 meter (30 inches). These measurements almost conform to moling practice in the Everglades. The depth to the impermeable layer was 1.22 meters (4 feet); the pressure at the drain outlets was assumed to be atmospheric. Values of spacing for intervals of 10, 15, 20, 40, and 60 feet were substituted in the formula. The resulting instantaneous drainage rates for various water table levels between 1.5 and 25.5 inches are given in Table 5. Table 5 also gives the value of time required to lower the water table through each 3-inch soil layer. These values were determined through the use of water release data in the manner described previously. In this application of water release data, a reference to Table 4 will show, for example, that the water released between the water table positions of 6 and 9 inches is 0.63 inch minus 0.30 inch, or 0.33 inch.

Since most water movement toward drains in a shallow soil must take place in a lateral direction, it follows that the horizontal conductivity should have a predominant influence on drainage rates. The anisotrophy of this soil as evidenced by the data of Table 3 imposes a restriction on lateral movement as compared with vertical in the zone below 12 inches. The values of K selected from Table 3 for use in all of the spacing formulas presented in this report are the averages of the horizontal values for the various layers below 12 inches. This relatively small design value of K (4.2 inches per hour) provides something of a safety factor inasmuch as spacing is a direct function of conductivity. The inclusion of horizontal K for the 0-to-12-inch layer would have resulted in a larger overall design value.

TABLE 5.--*Instantaneous drainage rates and water table drawdown times computed by Hooghoudt's tabular method for various water table positions and spacings of underdrains installed at a 30-inch depth in Everglades peaty muck*[1]

Water Table Position (inches)	Instantaneous Drainage Rate (inches/hour) Per Indicated Underdrain Spacing (feet)					
	10	15	20	40	60	100
1.5..............	1.589	0.770	0.433	0.116	0.052	0.017
4.5..............	1.343	.648	.368	.100	.043	.014
7.5..............	1.098	.525	.297	.078	.034	.012
10.5..............	.866	.420	.239	.065	.028	.010
13.5..............	.659	.324	.187	.048	.024	.008
16.5..............	.491	.245	.136	.036	.017	.005
19.5..............	.336	.158	.090	.026	.011	.004
22.5..............	.194	.096	.058	.016	.006	.003
22.5..............	.078	.044	.019	.006	.002	.001

Soil Layer (inches)	Drawdown Time (hours, not accumulative) Per Indicated Underdrain Spacing (feet)					
	10	15	20	40	60	100
0- 3.............	0.06	0.12	0.21	0.78	1.73	5.29
3- 6.............	.16	.32	.57	2.10	4.88	15.00
6- 9.............	.30	.63	1.11	4.23	9.71	27.50
9-12.............	.52	1.07	1.88	6.92	16.07	45.00
12-15.............	.73	1.48	2.57	10.00	20.00	60.00
15-18.............	1.10	2.20	3.97	15.00	31.76	108.00
18-21.............	1.96	4.18	7.33	25.38	60.00	165.00
21-24.............	2.63	5.31	8.79	31.88	85.00	170.00

[1] Drain radius of 2 inches.

Ernst and Boumans' Method

Probably the most convenient solution having application to tile drain spacing over a wide range of soil conditions is the nomographic method of Ernst and Boumans as reported by Visser (16). This method is also described by Van Schilfgaarde (14)..Knowing the hydraulic conductivity and the position of the drains with respect to the water table and impermeable layer, it is a simple matter to determine the instantaneous drainage rates for given spacings and water table levels. Drain size is not considered, and it must be assumed that the data do not reflect any restrictions to inflow as a result of drain size. The resulting rates may therefore vary from those obtained by the Hooghoudt method, depending on the extent to which drain size is assumed to vary in the latter.

In the interest of brevity the detailed drainage rates and drawdown times obtained by the nomographic solution are not presented. The accumulative drawdown times, however, for final water table levels of 18 and 24 inches are given in Table 6 for various spacings of closed drains.

Glover's Method

The Glover formula, reported by Dumm (4), was designed to meet conditions of a falling water table. Like the Ernst and Boumans' solution, there is apparently no restriction in drain size involved. The Glover formula for tile drain spacings is as follows:

$$S = \pi\,[KDt/f \ln (4y_o/y)]^{\frac{1}{2}},$$

where S = spacing in feet

K = hydraulic conductivity in feet per hour

D = average thickness of aquifer in feet = $d + y_o/2$ where d = distance between the drain and impermeable layer

t = drawdown time in hours

f = fraction of soil volume drained (see Table 4)

y_o = distance between initial water table and drain (vertically), in feet

y = vertical distance between final water table and a horizontal plane through the drain axes at a point midway between drains, in feet.

By substituting a range of values of t in this formula it was possible to construct curves defining the relationship between spacing and drawdown time for various values of final water table level. Interpolation from these curves for final water tables of 18 and 24 inches, respectively, resulted in the total drawdown times given in Table 6.

TABLE 6.--*Total time required to lower a water table from the ground surface to 18- and 24-inch depths for various spacings of underdrains in Everglades peaty muck as determined separately by the Hooghoudt, Nomographic, and Glover solutions*[1]

Drain Spacing (feet)	Drawndown Time (hours) From Ground Surface to--					
	18 inches			24 inches		
	Hooghoudt	Nomographic	Glover	Hooghoudt	Nomographic	Glover
10.............	2.9	2.2	1.5	7.4	5.5	2.8
15.............	5.8	5.2	3.2	15.3	11.8	6.4
20.............	11.3	9.3	5.7	27.4	20.0	10.1
40.............	39.0	32.2	23.0	96.3	70.8	43.0
60.............	84.1	64.8	52.0	229.2	139.8	96.0

[1] Drain radius of 2 inches specified by Hooghoudt as assumed; no drain size specified for the other solutions.

Comparison of Closed Drain Calculations

Table 6 essentially gives a comparison of the times required to lower a water table from the surface to 18 and 24 inches depth as computed by the three methods using the same basic soils data. For each drain spacing, the Hooghoudt tabular method gives the most conservative, or longest, drawdown time requirements, the nomographic method some less, and the Glover solution considerably less. The Hooghoudt method assumes a drain size of 2 inches radius whereas both the nomographic and Glover solutions do not specify a drain size. It appears logical that the higher values given by the Hooghoudt method reflect essentially the effect of sharply converging flow lines and restricted inflow due to drain size.

If either the Hooghoudt or the nomographic solution is assumed to be reasonably correct, the Glover formula is seen to overestimate spacings. This conclusion is in accord with the critique given by Van Schilfgaarde (14) and would seem to invalidate this method for field design where a safety factor is desirable.

Interspacing Open Drains

Ellipse Formula

An adaptation of the ellipse formula of Colding (3) has been applied to the problem of water table control by ditches. This formula is as follows:

$$n = \frac{4\, H_o^2\, K}{S^2},$$

where n = drainage rate in inches per hour

H_o = height of the water table above the impermeable layer, in inches

K = hydraulic conductivity in inches per hour

S = spacing in inches.

This particular formula is valid only where the ditch penetrates to the impermeable layer and the height of the water in the ditch is zero. These conditions of course are not strictly met in the field, but the formula enables a rational approach to a problem that does not lend itself to an exact solution.

Drainage rates and water table drawdown times for various water tables and soil layers, respectively, were determined at various spacings by the formula of Colding (Table 7), as was done for closed drains by the formula of Hooghoudt (Table 5). The total accumulative drawdown times for final water table levels of 18 and 24 inches are given in Table 8 for various spacings. These values for ditches are seen to be in the same order of magnitude as those obtained for closed drains by the Glover method. In Van Schilfgaarde's reasoning (14) this agreement would stem from Glover's failure to account for convergence of streamlines near the closed drains. Colding's method tends to exaggerate flow values for open ditches.

Drain Spacing in the Everglades

The three methods presented pertaining to underdrains apply to moles only when they are unobstructed. When they are free flowing and do not reduce to diameters less than 2 inches, the Hooghoudt data presented should be safe.

The choice of 18- and 24-inch depths as final water table levels is based largely on observations of plant response by various workers in the area. This may be further substantiated by a consideration of the air space existing above such water tables. Kopecky (8, 9) has indicated that the minimum air space requirements vary between 6 and 20 percent, depending on the crop grown. The data of Table 1 reveal that equilibrium air contents in this soil in the important rooting zone between the surface and depth of 12 inches range from 9 to 20 percent for an 18-inch water table, and from 15 to 23 percent for a 24-inch water table. Obviously the rooting habits of specific crops must be considered in setting the limits for final water table levels.

If a maximum time limit of 48 hours is set for water table drawdown, it is apparent that mole spacings should not exceed about 40 feet and spacings of ditches 60 feet. Where deep seepage, up or down, exists, these values should be adjusted accordingly. The use of ditches alone for water table control under these conditions would seem to be unfeasible because of the excessive area that ditches require.

The foregoing analysis deals with only one aspect of the drainage problem, namely, that of rapid water table drawdown after rains. The problem of drainage, however, should be reconciled with that of subirrigation, for in south Florida the same system is customarily used for both. This consideration may result in modifications of water control design, although spacings close enough for drainage are generally in excess of irrigation needs.

Where instability of mole drains is a problem, the feasibility of installing permanent tile drains should be investigated. The use of low-cost plastic mole liners may, in the near future, prove economical. The practicability of these suggestions may in large measure be evaluated through application of flow formulas and basic soil water data. It is important, of course, that methods of solution be carefully examined for applicability to existing field conditions.

TABLE 7.--*Instantaneous drainage rates and water table drawdown times computed from Colding's ellipse formula for various water table positions and spacings of ditches penetrating to rock in Everglades peaty muck*

Water Table Position (inches)	Instantaneous Drainage Rate (inches/hour) Per Indicated Ditch Spacing (feet)						
	10	15	20	40	60	100	150
1.5	2.522	1.121	0.631	0.158	0.070	0.025	0.011
4.5	2.207	.981	.552	.138	.061	.022	.010
7.5	1.913	.850	.478	.120	.053	.019	.009
10.5	1.640	.729	.410	.103	.046	.016	.007
13.5	1.388	.617	.347	.087	.039	.014	.006
16.5	1.157	.514	.289	.072	.032	.012	.005
19.5	.947	.421	.237	.059	.026	.009	.004
22.5	.758	.337	.190	.047	.021	.008	.003
25.5	.590	.262	.148	.037	.016	.006	.003

Soil Layer (inches)	Drawdown Time (hours, not accumulative) Per Indicated Ditch Spacing (feet)						
	10	15	20	40	60	100	150
0- 3	0.04	0.08	0.14	0.57	1.29	3.60	8.18
3- 6	.10	.21	.38	1.52	3.44	9.54	21.00
6- 9	.17	.39	.69	2.75	7.17	17.37	36.67
9-12	.27	.62	1.10	4.37	9.78	28.12	64.28
12-15	.35	.78	1.38	5.52	12.30	34.29	80.00
15-18	.47	1.05	1.87	7.50	16.88	45.00	108.00
18-21	.70	1.57	2.78	11.19	25.38	73.33	165.00
21-24	.67	1.51	2.68	10.85	24.29	63.75	170.00

TABLE 8.--*Total time required to lower a water table from the ground surface to 18- and 24-inch depths for various spacings of ditches in Everglades peaty muck as determined by the Colding ellipse solution*

Ditch Spacing (feet)	Drawdown Time (hours) From Ground Surface to--	
	18 inches	24 inches
10	1.4	2.8
15	3.1	6.2
20	5.5	10.9
40	22.2	44.3
60	50.9	100.5
100	137.9	275.0
150	318.1	653.1

SUMMARY

Basic physical data for Everglades peaty muck including moisture tension relationships and saturated hydraulic conductivities have been examined for their applicability to solution of water control problems.

The equilibrium air contents above stationary water tables were computed, and the complications affecting their value in estimating storage capacity and drainage water release discussed.

The use of drainage rates to estimate required water table drawdown time was evaluated. Water release data divided by instantaneous drainage rates determined through use of the Hooghoudt and the Ernst-Boumans solutions for successive steady state water tables gave a measure of time required for the water surface to pass through small layers above closed drains. Similarly, the drawdown times for ditches were estimated from an adaptation of Colding's ellipse formula.

The application of Glover's nonsteady-state formula yielded drawdown times considerably less than those obtained by other methods for closed drains.

Overall results indicated that underdrain spacings at a 30-inch depth should not exceed about 40 feet, and ditches penetrating to the impermeable layer should not exceed 60 feet where either system must be depended upon to lower water tables to safe depths within 48 hours after profile saturation.

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